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COMPARISON OF ACI, IS AND DOE METHODS OF CONCRETE MIX DESIGN

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ABSTRACT
The American Concrete Institute 211-92 mix design proportioning method (ACI method) for normal concrete was compared with two other methods British DOE Mix design proportioning method (DOE method) and the Indian Standard mix design proportioning method - IS 10262-82 (IS method) in order to evaluate the method that gave the best workability, cost efficiency and met the targeted mean compressive strength (TMCS) within 28 days curing period. The proportioning of the materials used in the batching of fresh concrete was adequately evaluated using ACI 211-91. 75 concrete members were cast using 100×100×100 mm moulds and the compressive strength for 7, 14, 21, and 28 days were obtained after the cubes were cured in water. Studies were done to obtain the relationship between the compressive strength and Water-cement ratio, cement content, workability, Aggregate– cement ratio, fine aggregate content, coarse aggregate content and cost analysis was evaluated and compared for the three methods of mix design. The ACI method and IS methods were easier to proportion compared to the DOE method which was cumbersome. The compressive strength of the ACI method and IS methods met the TMCS but the DOE method did not meet the TMCS for the M15, M20, M25, M30 and M40 grades of concrete. The ACI method was more cost effective than the IS method. The ACI method was cheaper than the IS method by; 14.94%, 12.18%, 12.55%, 12.93% and 4.10% for the M15, M20, M25, M30 and M40 concrete grades respectively. The ACI method was thus, recommended as first choice proportioning method for the group studied.
Keywords: *ACI method, aggregate cement ratio, DOE method, IS method, normal concrete.*

INTRODUCTION

The process of selecting and characterizing properly the constituent materials for concrete and determining their amounts with the intention of achieving the desired targeted strength and properties is called proportioning of concrete mixture (Chandrakar, and Mishra (2012)). Concrete mix design and proportioning have undergone a lot of modifications over the years because of its utilization as a construction material in the world today. Concrete is utilized in the construction of infrastructures to meet up with the development in the 20th century (Mehta and Burrows (2011)). In order to keep up with this trend various countries and nations have developed their own standards in proportioning concrete mixture in order to achieve the following: good workability of the concrete mixture, durability, high strength, best appearance required, and most importantly cost efficiency (utilization of the least amount of materials to produce maximum compressive strength and desired properties) can only be achieved with the careful selection of the appropriate design and proportioning of the concrete mixture.

The authors want to determine a workable, effective and efficient mix design for proportioning normal concrete that will give maximum targeted strength at the best price.

Various Methods of Proportioning Concrete

In order to proportion concrete mixtures efficiently the right mix design method must be deployed. In general the method to be adopted is aimed at utilizing the least amount of concrete paste to obtain the desired qualities of concrete listed above. Some of the various proportioning methods include; American Concrete Institute 211-91 (ACI Method), British DOE method (DOE method), Fineness Modulus Method, Maximum Density Method, Surface Area Method, India Standard-10262-82 method (IS method) to mention a few. (Shettty, 2005). For this study the author(s) focused on three mix design methods which are: ACI Method, DOE Method, and IS method. These mix design proportioning methods are based on charts and graphs mathematically correlated together. Though they apply the same concept, there are a lot of differences between these three mix design proportioning methods for designing concrete mixtures. The three different proportioning methods differ from each other in terms of the quantities of materials required to produce the concrete.

Criteria for Selecting a Mix Proportion

Determination of Grade of Cement

The grade of the cement to be utilized for the concrete mixture will have to be must be specified as this will have a profound effect on the strength of the concrete to be produced (Adewole *et al.*, 2014).

Aggregate characteristics

The aggregates normally utilized for the production of concrete are fine and coarse aggregates. The characteristics of these aggregates go a long way to determine the strength of the concrete. Some of the characteristics of the aggregates to be evaluated include: gradation, maximum size, nominal maximum size, absorption, specific gravity, bulk density, percent voids, percent moisture content and mechanical properties. The aggregates properties have effect on the properties of the concrete. Thus, a lot need to be done to ensure that the aggregates meet required standards so as not to compromise the integrity of the concrete (Konsul and Darwin (1997).

Water-cement ratio

Water-cement ratio is usually used synonymously with Water-cementitious ratio, but the two are not the same. Water-cement ratio (w/c), is the ratio of water to cement while water cementitious ratio is the ratio of water to cement and any other cementitious material that may be included in the cement mixture (some of these cementitious materials include fly ash, silica fume, natural pozzolans, slag etc. Cement ratio plays a critical role in the strength of concrete, for a normal concrete used in construction with adequately graded and sound aggregate the strength is inversely related to the water-cement ratio of the mix (Ejiogu *et al.,* 2018).

Consolidation and workability of concrete

Workability of cement is the ability of cement to flow, placed, consolidated, compacted and finished. To determine the workability of cement a slump test is usually carried out. For the specific design mix proportion adopted for study, defined slumps for desired workability of the cement has been represented on tables and graphs. The desired values can be picked form the graphs to formulate the mix proportions and trial batches tested to see if they meet desired results.

Environmental conditions

The environment the concrete may be exposed to will also affect the mix proportion to adopt. These conditions may include; mild, moderate or severe exposure to freezing and deicing agents. These conditions will determine the air content to be adopted and this will affect the mix proportion to be adopted. The amount of air required to provide adequate freeze thaw resistance which depends on the maximum aggregate size and the degree of exposure. Mortar content of concrete normally decreases with increase in maximum aggregate size reducing the air content and producing a higher strength concrete (Afsar, 2012).

Utilization of admixture

Admixtures may be defined as a materials, other than the main components of concrete (cement, water, aggregates) introduced into the concrete mixture before, immediately or after mixing (Shetty, 2005). E.g. plasticizers, retarders, pozzolans, etc. However, additives are materials added at the time of grinding the cement in the clinker at the cement factory e.g. gypsum, triethanolamine (TEA), ethylene glycol, oleic acid, and dodecyl- benzene sulfonate. The work of Chandrakar and Mishra (2012) showed that ACI and IS methods of proportioning concrete mixture gave higher compressive strength and met the targeted mean compressive strength (TMCS) at 28days cure, but the DOE method of mix design did not meet the TMCS for the various grades of concrete due to lower cement content, higher water content, higher aggregate cement ratio and higher water –cement ratio compared to the other two methods. Konsul and Darwin (1997) evaluated the affect of water cement ratio, on the strength of the concrete for different cure days, and established that the strength of concrete increased as the water cement ratio reduced. Baskaran and Gopinath (2012) studied the applicability of ACI and DOE mix design methods on paving blocks and showed that the paving blocks casted using ACI mix proportions have compressive strengths that are higher than the compressive strength requirements of Sri Lankan standard for paving blocks. In addition the paving blocks produced using the DOE mix design method met the compressive strength that met the requirements of classes 2, 3 and 4 roads.

MATERIALS AND METHOD

Materials

Cement (cmt)

Ordinary Portland Lime Stone Cement, Grade 42.5, Type - I, was used in the mix proportion for this study. The chemical and physical properties of the cement are shown in Tables 1 and 2 respectively.

Fine aggregates (FA)

The fine aggregate was natural river sand obtained from Ahmadu Bello University (ABU) Dam, in Zaria, Kaduna State in Nigeria. Sample of the fine aggregates were collected and sieved with 5mm sieve size to remove deleterious materials in accordance with ASTM C 33, which limits the permissible amounts of deleterious substances found in the fine aggregate. The fine aggregate were kept at ambient temperature in the laboratory and was utilized under surface saturated conditions. Samples were kept and collected in accordance with ASTM D 75-03. The maximum size, nominal maximum size and fineness modulus was 5 mm, 4.75 mm and 3.14 mm respectively. The particle size analysis of the fine aggregate is shown in Table 3.

Coarse aggregate (CA)

The coarse aggregate were obtained from a quarry site opposite Nigerian College of Aviation Technology (NCAT) along Sokoto Road Zaria in Kaduna State. Nigeria. Samples of the coarse aggregates were collected and were sieved through the 20 mm sieve size and retained on the 5mm sieve to remove deleterious materials according to ASTM C 33. The coarse aggregates were then kept at ambient temperature in the laboratory to attain surface dry conditions. Samples were kept and collected according to ASTM D 75-03. The maximum size, nominal maximum size and fineness modulus was 20 mm, 19.5 mm and 6.95 respectively. The particle size analysis of the coarse aggregate is shown on Table 4.

Mixing and curing water

Tap water was utilized for the study and was supplied from ABU Dam.

Method

Proportioning of concrete mixture

The proportioning of the concrete mixture involved the establishment of specific characteristics the concrete mixture will have, area of application and properties of aggregates utilized (mix design parameters shown on Table 5 and 6). These data were then utilized for the design and proportioning of various grades of concrete blocks (the mix design proportion utilizing the ACI, DOE and IS methods are shown in Table 7). The mix proportion that provided the best economy, ease of processing, good workability, consistency and strength was adopted. Consideration was given to the mix design proportion that had good tolerance for the addition of admixture in case such may be introduced into the concrete mix in the future. Normal concrete grades of M15, M20, M25, M30, M40 were produced using ACI, DOE and IS methods of proportioning concrete. The compressive strength of the concrete blocks were tested for 7, 14, 21 and 28 days cure periods.

Workability of fresh concrete

Slump test was utilized to test the workability of the fresh concrete mixture.

Casting and curing of test specimen

Casting was done using the 100×100×100 mm metallic mold and cured under water for 7, 14, 21 and 28 days respectively. Compressive strength test were carried out for each of these curing days by placing the cured concrete samples in compression testing equipment (STYE 200). Other properties of the concrete were evaluated and recorded.

Table 1: Chemical properties of OPC utilized in the study

Constituents	% Weight
lime	60.20
Silica	20.4
Iron Oxide	3.48
Sulfite	2.32
Magnesium Oxide	1.49
Loss on Ignition	0.75
Lime Saturation Factor	0.92
Insoluble Residue	0.36
Compounds on Gelation of cement using Bogue Equation	
Tricalcium silicate	50.20
Dicalcium Silicate	21.50
Tri calcium aluminate	9.22
Tetra calcium aluminoferrite	10.89

Table 2: Physical properties of OPC utilized in the study

Properties	OPC
Specific gravity	3.15
Bulk density	1452 Kg/m^3
Initial setting time	35 mins
Final setting time	300 mins
Soundness (%)	0.18
Fineness	223 m^3/Kg
3 days compressive strength (MPa)	25.00
7 days compressive strength (MPa)	33.00
14 days compressive strength (MPa)	38.80
21 days compressive strength (MPa)	42.00
28 days compressive strength (MPa)	45.00

Table 3: Particle size analysis of fine aggregate

Mass FA = 2 Kg Sieve size (mm)	Mass Retained	% Mass Retained	% Mass Passed	Cumulative % Retained
10.00	0	0	100	0
5.00	0	0	100	0
4.75	80	4	96	4
2.35	278	14	82	18
1.18	537	27	55	45
600	438	22	33	67
300	318	16	17	83
150	259	13	4	96
Pan	79	4	-	-
Total	1989	100		314 Fineness Modulus=314/100=3.14

Table 4: Particle size analysis of coarse aggregate

Mass CA = 4 Kg Sieve size (mm)	Mass Retained (g)	% Mass Retained	% Mass Passed	Cumulative % Mass Retained
25.00	0	0	100	0
19.00	0	0	100	0
12.5	2875	72	28	72
9.5	917	23	5	95
4.75	198	5	0	100
2.36	0	0	0	100
1.18	0	0	0	100
0.60	0	0	0	100
0.30	0	0	0	100
0.15	0	0	0	100
Pan	0	0	0	100
Total	3390	100		$\sum$695 Fineness Modulus=695/100=6.95

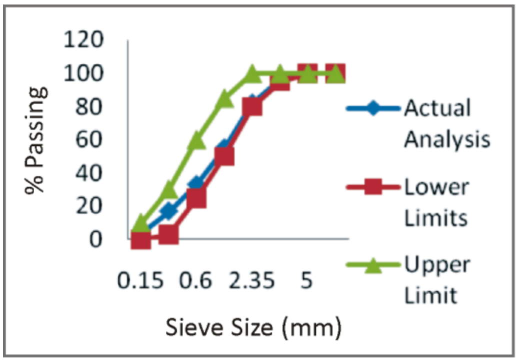

Figure 1: Gradation of fine aggregate

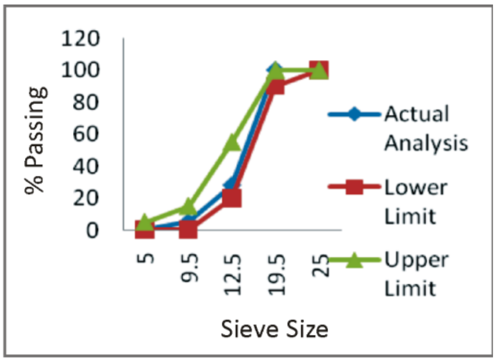

Figure 2: Gradation of coarse aggregate

Table 5: Concrete mix design parameters

S/N	Properties	Values
1.	Targeted compressive strength	M15, M20, M25 M30, M35, M40 MPa at 28 days
2.	Type of cement	ASTM Type I
3.	Specific gravity of cement	3.15
	maximum size of aggregate	20 mm
4.	Nominal maximum size of coarse aggregate	19 mm
5.	Workability	25-75 mm
6.	Exposure	Mild
7.	Degree of quality control	Good
8.	Type of coarse aggregate	Crushed Lime Stone

Table 6: Physical properties of aggregates

S/N	Physical properties	Values
1.	Specific gravity	
	fine aggregate	2.65
	coarse aggregate	2.52
2.	Loose bulk density	
	fine aggregate	1630 kg/m³
	coarse aggregate	1.542 Kg/m³
3.	Compacted bulk density	
	fine aggregate	1750 Kg/m³
	coarse aggregate	1647 Kg/m³
4.	Water absorption	
	fine aggregate	1.10%
	coarse aggregate	1.20%
5.	Fineness modulus	
	fine aggregate	3.14
	coarse aggregate	6.95
6.	Percent free surface moisture	
	fine aggregate	1.10%
	coarse aggregate	1.10%
7.	Workability desired slump	25-75 mm
8.	Air content (moderate exposure)	3.5%
9.	Chemical admixture utilized	Non

RESULTS AND DISCUSSIONS

Table 7: The ACI, DOE and IS methods of mix design proportions for various grades of concrete

S/N	Method	Grade of Concrete	Targeted Mean Compressive Strength (TMCS) (MPa) at 28 days	W/C	Cement (CMT) Content (kg/m³)	Water Content (Kg/m³)	FA Content (Kg/m³)	CA Content (Kg/m³)	TAC (Kg/m³)	TAC/CMT
		M15	22.00	0.64	262.50	162.36	763.08	1085.80	1848.88	7.04
1	ACI	M20	27.00	0.54	311.11	162.71	721.35	1085.80	1807.15	5.81
	Method	M25	33.50	0.42	400.00	163.39	632.45	1085.80	1718.25	4.30
		M30	38.50	0.40	420.00	163.54	627.93	1085.80	1713.53	4.07
		M40	45.00	0.30	560.00	164.65	502.04	1085.80	1587.84	2.80
		M15	23.00	0.83	253.00	204.04	810.70	1190.89	2001.59	7.91
	British	M20	28.25	0.73	287.67	205.31	756.73	1209.11	1965.84	6.83
2	Doe	M25	33.69	0.62	338.71	205.81	698.15	1215.49	1913.64	5.65
	Method	M30	38.00	0.56	375.00	205.52	646.68	1229.55	1876.23	5.00
		M40	50.00	0.44	477.27	206.47	539.30	1232.25	1771.55	3.71
		M15	20.78	0.50	383.32	187.79	566.00	1180.60	1746.60	4.56
		M20	26.60	0.48	399.17	187.82	563.31	1170.71	1734.02	4.34
3	IS Method	M25	31.60	0.38	504.21	188.01	533.02	1112.63	1645.65	3.26
		M30	36.60	0.36	532.22	188.06	515.18	1096.89	1612.07	3.03
		M40	48.25	0.34	563.22	188.12	514.05	1079.21	1593.26	2.83

KEY: FA = Fine Aggregate, CA = Coarse Aggregate, TAC = Total Aggregate Content., TMCS = Targeted Mean Compressive Strength @ 28 days cure, TMCS here specifically means the compressive strength the particular grade of concrete is supposed to attain within 28 days cure in water. Emphasis on 28 days because it is expected that the concrete will achieve its maximum strength within 28 days.

Table 8: Results for compressive strength for various grades of concrete at different cure days

S/N	Method	Grade of concrete	Targeted mean compressive strength (TMCS) (MPA) at 28 days	W/C	Slump (mm)	7 days compressive strength	14 days compressive strength)	21 days compressive strength	28 days compressive strength	Ave density of five cubes sample (Kg/m^3)
		M15	22.00	0.64	33	15.62	18.04	21.56	22.11	2273.74
1		M20	27.00	0.54	30	19.71	22.41	25.38	28.19	2280.97
	ACI	M25	33.50	0.42	38	24.79	28.48	31.16	35.47	2281.64
	Method	M30	38.50	0.40	40	26.95	33.88	37.73	38.84	2297.07
		M40	45.00	0.30	45	33.75	38.70	43.65	46.13	2408.63
		M15	23.00	0.83	40	11.96	14.26	16.56	20.00	2458.82
	British	M20	28.25	0.73	45	17.80	21.47	24.01	26.27	2458.16
2.	Doe	M25	33.69	0.62	43	20.00	25.00	26.00	29.00	2456.75
	Method	M30	38.00	0.56	45	23.00	25.84	29.64	32.30	2455.29
		M40	50.00	0.44	50	29.00	32.50	39.00	42.50	2456.48
		M15	20.78	0.50	30	14.55	17.03	20.16	20.96	2231.71
3	IS	M20	26.60	0.48	35	18.72	22.61	26.07	27.88	2321.01
	Method	M25	31.60	0.38	38	22.75	26.86	31.13	33.12	2337.87
		M30	36.60	0.36	42	27.45	31.12	34.04	37.12	2335.35
		M40	48.25	0.34	35	36.67	39.57	44.87	48.30	2337.60

Note: The water content indicated in the results was obtained by considering moisture content and absorption of the aggregates. Water content obtained in result = Water Content (SSD condition) – [(F.Acr /1.02X0.09) – (C.Acr /1.011X – 0.001)], where F.Acr and C.Acr are Fine aggregate content and Coarse aggregate contents displayed in Table 4.0 Workability/slump fell within the recommended values for the mix design utilized in Table 6 for all the proportion methods and grades of concrete.

Mix design methods and compressive strength for various grades of concrete

Tables 7 and 8 shows the mix design methods and compressive strength for various grades of normal concrete produced using the ACI, IS and DOE design methods and they include: M15, M20, M25, M30 and M40. The designation M25 means that after 28 days the concrete compressive strength should not be less than 28 MPa, and this also goes for other grades of concrete that were produced as indicated in Tables 7 and 8, more so the concrete must meet its TMCS. The results shown in the graphical representations as indicated in Figure1 to Figure 27 were drawn from Tables 7 and 8.

Relationship between compressive strength and age of curing of various grades of concrete

Figures 3, 4, 5, 6 and 7 showed the compressive strength of various grades of concrete with the number of curing days. The figures showed that the compressive strength of concrete increased as the number of curing days increased for the M15, M20, M25, M30 and M40 concrete grade respectively. The ACI and IS methods exceeded the TMCS compressive strength for 7, 14, 21 in 28 days respectively, while the DOE method did not meet the expected TMCS for all the grades of concrete produced. This may be attributed to the higher water cement ratio utilized by the DOE method. (Chandrakar and Mishra, 2012). The higher strength of the concrete proportioned using ACI and IS methods can be attributed to the lower air voids in the concrete.

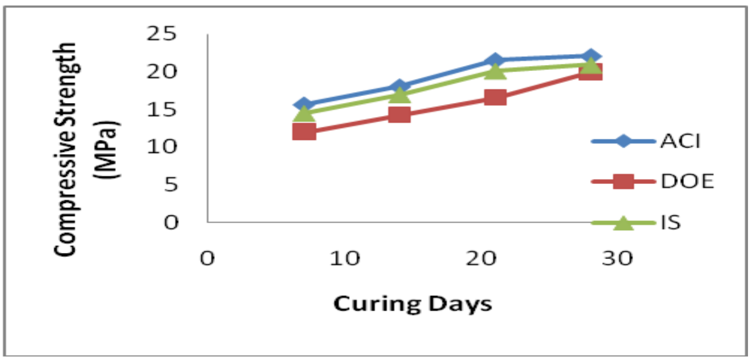

Figure 3: Compressive strength Vs. curing days for M15 grade concrete

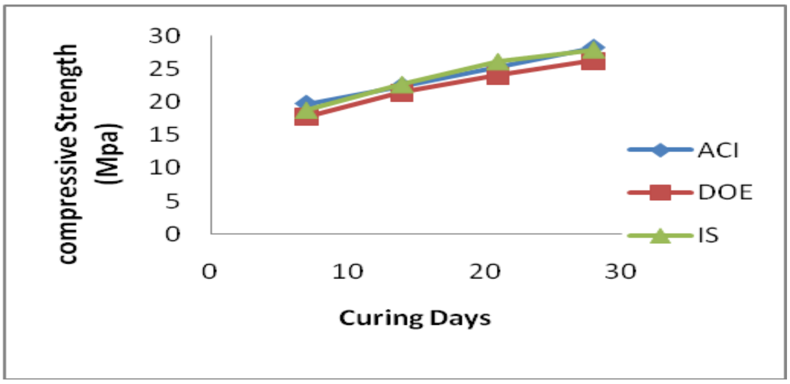

Figure 4: Compressive Vs. curing days for M20 grade concrete

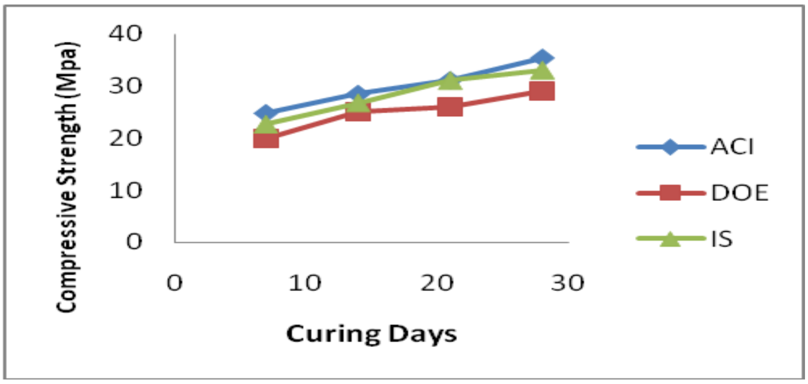

Figure 5: Compressive Vs curing days for M25 grade concrete

Relationship between compressive strength and water cement ratio

The relationship between compressive Strength and water cement ratio are shown in Figures 8, 9, 10 and 11 for various grades of concrete. The results showed that there was increase in compressive strength as water cement ratio reduced for 7, 14, 21 and 28 days cure. The ACI method had the lowest water cement ratio. The water cement ratio of the ACI and IS methods decreased by 31.82% and 22.73% respectively compared to that of the DOE method for the highest compressive strength attained by each of the three methods shown in Figure 11 for 28 days curing period. Similarly the water cement ratio of the ACI method is lower by 11.8% compared to that of the IS method for 28days curing at the highest compressive strength attained by each of the two methods as indicated in Figure 11. The higher compressive strength exhibited by the ACI and IS methods can be attributed to the lower air voids in the concrete, which reduced when the water content reduced. (Shetty, 2005).

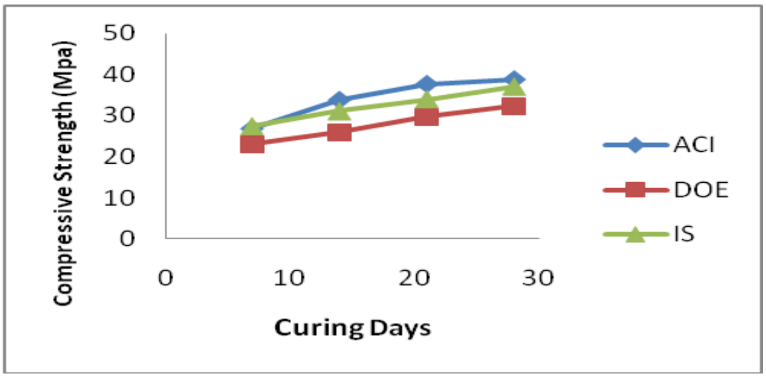

Figure 6: Compressive Vs curing days for M30 grade concrete

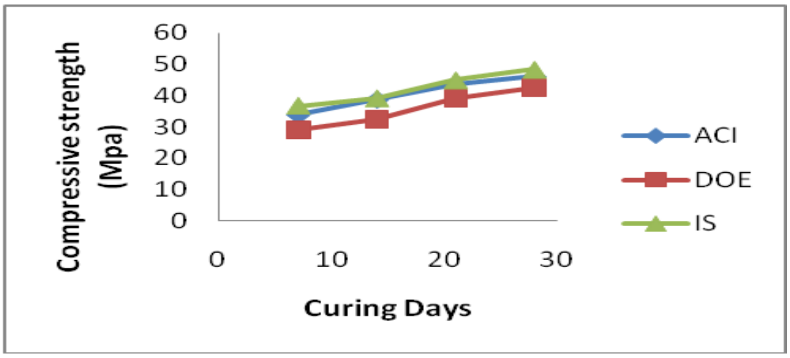

Figure 7: Compressive Vs curing days for M40 grade concrete

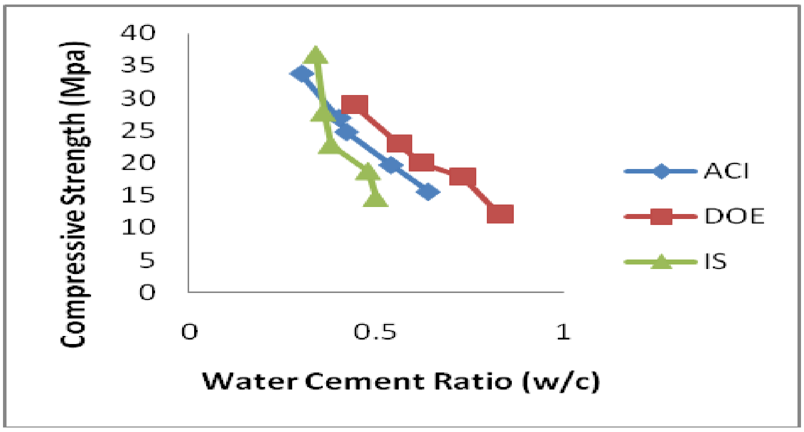

Figure 8: Compressive strength Vs water cement ratio for 7 days curing period

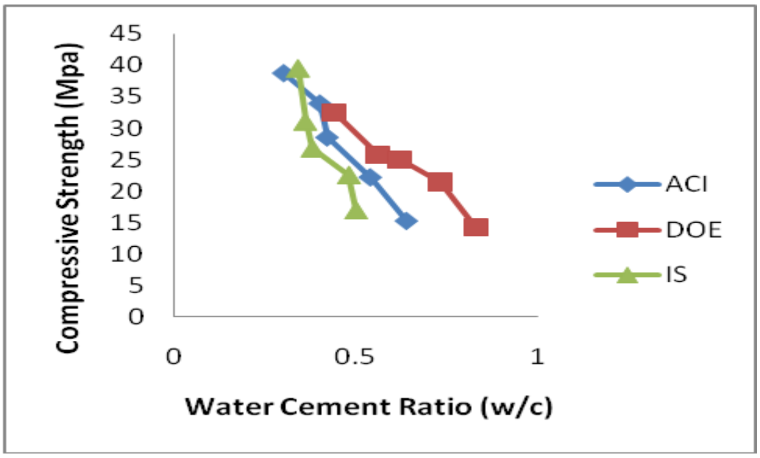

Figure 9: Compressive strength Vs water cement ratio for 14 days curing period

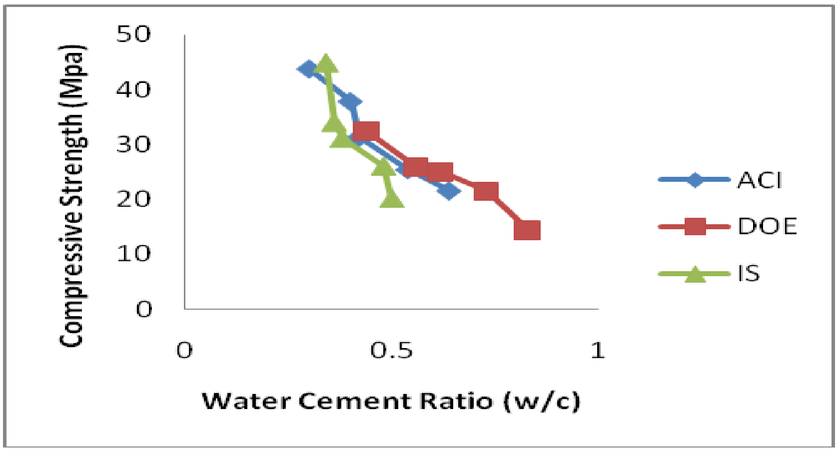

Figure 10: Compressive strength Vs water cement ratio for 21 days curing period

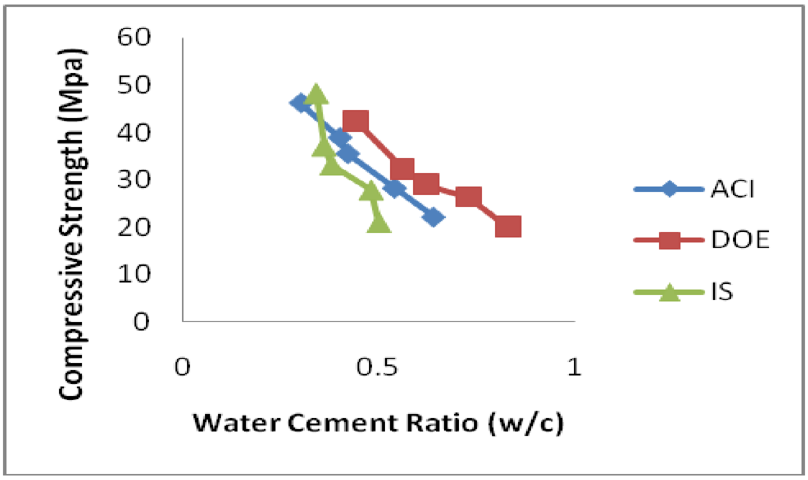

Figure 11: Compressive strength Vs water cement ratio for 28 days curing period

Relationship between compressive strength and cement content

Figures 12, 13, 14, 15 showed the trend between compressive strength and cement content. The ACI method and The IS methods utilized more cement than the DOE method. The ACI an IS methods met the TMCS for all the grades of concrete while the DOE method failed to meet the TMCS. The ACI method utilized 17.33% more cement than the DOE method and this resulted in its higher compressive strengh compared to DOE at 28 days period as indicated in Figure 15. The IS method utilized 18% more cement than the DOE method and this also resulted in its higher compressive strength compared to DOE at 28 days period as indicated in Figure 15. The IS method utilized more cement than the ACI and DOE methods indicating that the IS method is the more expensive mix design method because cement contributes a significant percentage to the cost component of the concrete mixture.

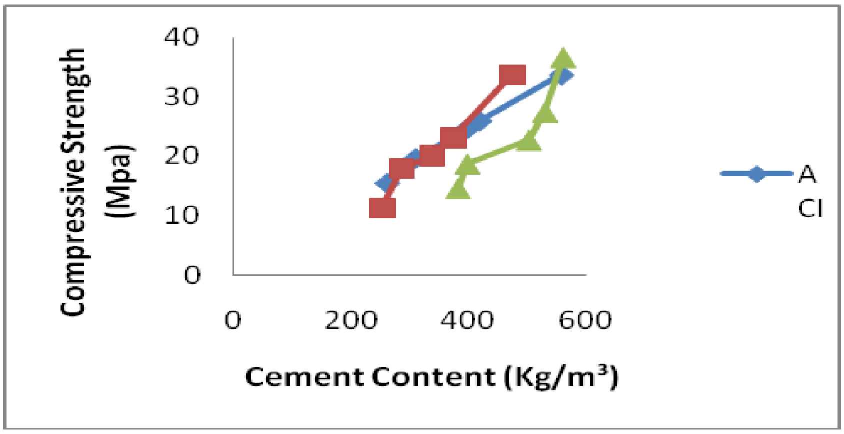

Figure12: Compressive strength Vs cement content for 7 days curing period

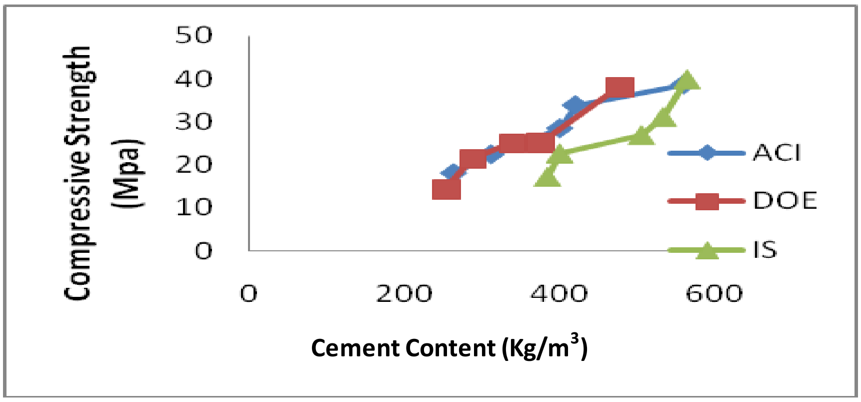

Figure 13: Compressive strength Vs cemennt content for 14 days curing period

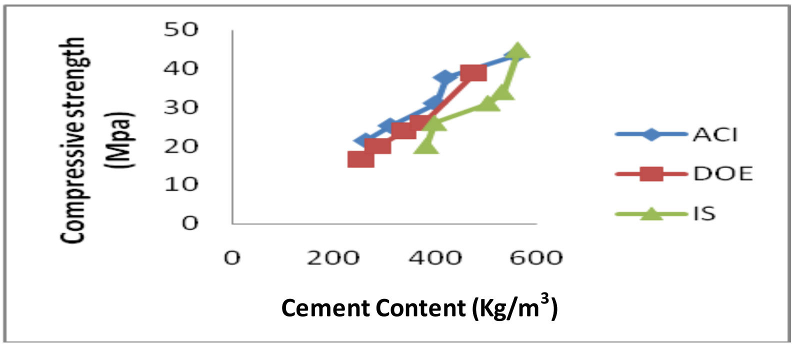

Figure14: Compressive strength Vs cement content for 21 days curing period

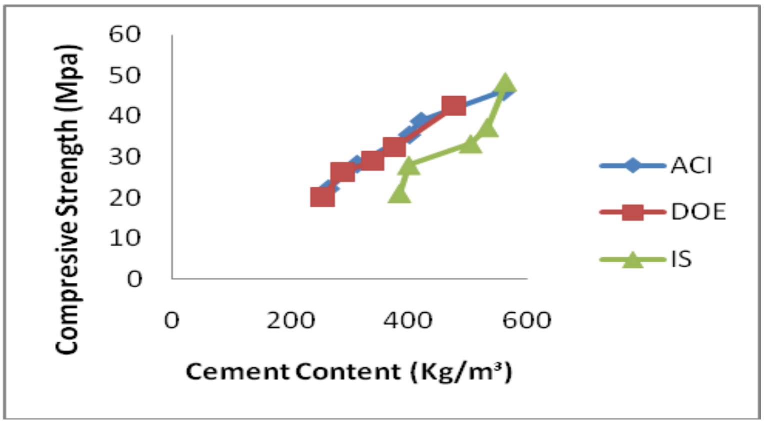

Figure 15: Compressive strength Vs cement content for 28 days curing period

Relationshio between compression strength and aggregate cement ratio

Figures 16, 17, 18 and 19 shows that the compressive strength increased as the aggregate cement ratio decreased for the 7, 14, 21 and 28 days curing period for all methods. This is beacause as the aggregate to cement ratio reduced there was more cement available to fill the voids in the concrete mix, making a good paste cover over the surface of the aggregate. This improved bonding during hydration of the cement as it cured. ACI and IS methods had lower aggregate to cement ratio than the DOE method thus, the ACI and IS methods had more cement to fill the voids and cover the surface of the aggregate in the concrete mix. The improved cement bond and less viods in the concrete mix gave higher compressive strength in the ACI and IS methods over the DOE method. The DOE method did not meet the TMCS for all the grades of concrete produced. The IS and ACI methods had a lower aggregate to cement ratio of 28.27% and 32% repectively compared to DOE method at the highest compressive strength attained by each of the three methods as indicated in Figure 19. The IS method had a lower aggregate to cement ratio of 1.07%, compared to ACI metod at the highest compressive strength attained by each of the two methods as indicated in Figure 19.

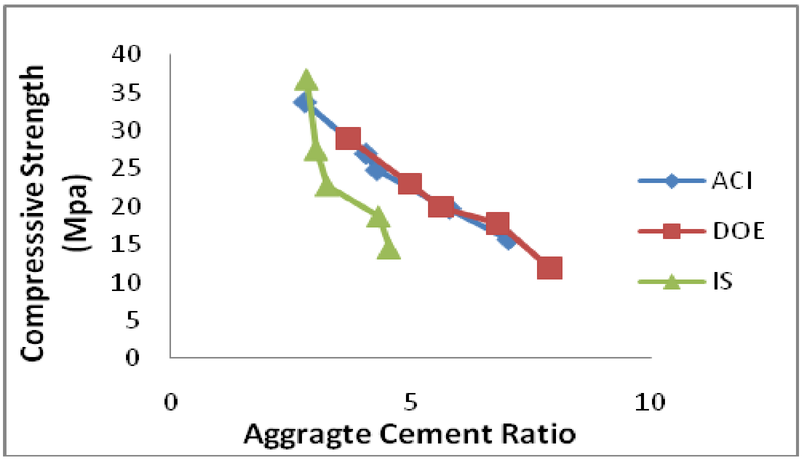

Figure 16: Compressive strength Vs aggregate cement ratio for 7 days curing period

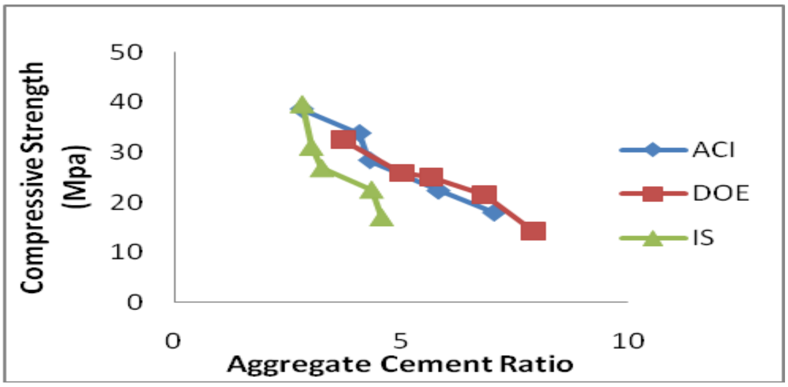

Figure 17: Compressive strength Vs aggregate cement ratio for 14 days curing period

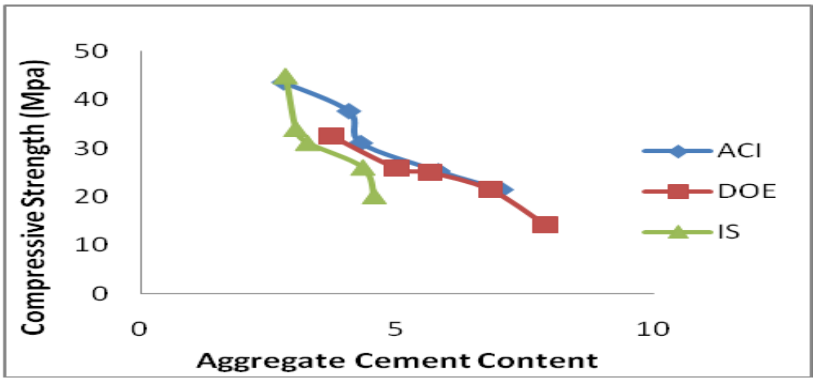

Figure 18: Compressive strength Vs aggregate cement ratio for 21days curing period

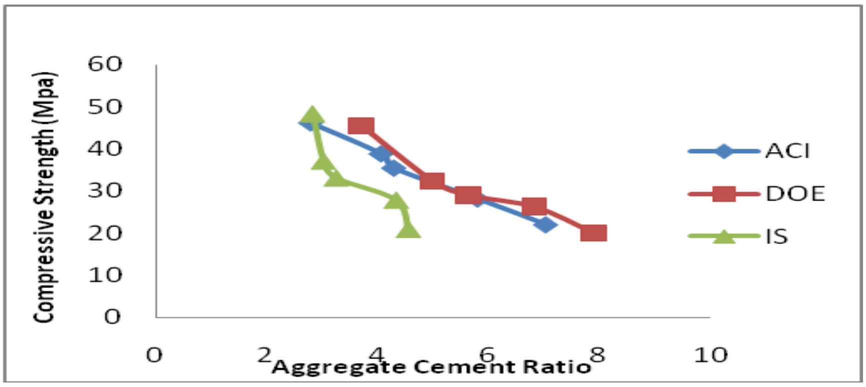

Figure 19: Compressive strength Vs aggregate cement ratio for 28 days curing period

Relationship between compresive strength and fine aggregate content

Figures 20, 21, 22, and 23 depicts that the compressive strength increased as the amount of fine aggregate utilized in the mix proportion reduced. Less fine aggregate content required less water and more cement was available to cover the surface area of the fine aggregates to produce a workable concrete mix. Less water directly means less voids are avalable in the concrete increasing the strength (Afsar, 2012). The DOE method had the highest amount of fine aggregate. The ACI method had a lower fine aggregate content of 7.36% compared to that of the DOE method at 28days curing period for the highest compressive strength attained by each of the two methods shown in Figure 23. The IS method had a lower fine aggregate content of 4.91% compared to that of the DOE method at 28days curing period shown in Figure 23. The ACI method had a lower fine aggregate content of 2.33% compared to that of the IS method at 28days curing period as indicated in Figure 23. Despite the slight reduction in the fine aggreagate content, the IS method still met its TMCS.

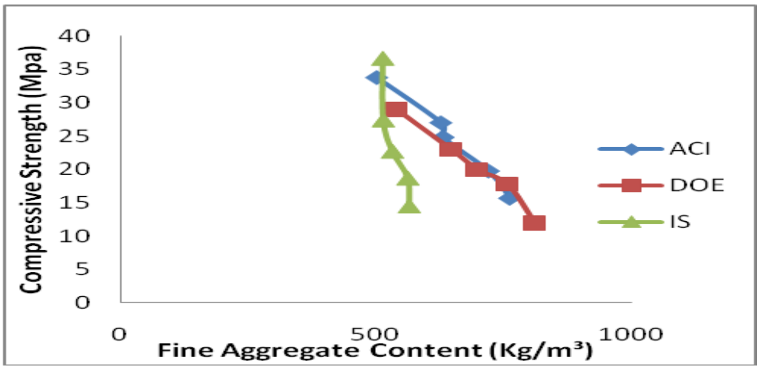

Figure 20: Compressive strength Vs fine aggregate content for 7 days curing period

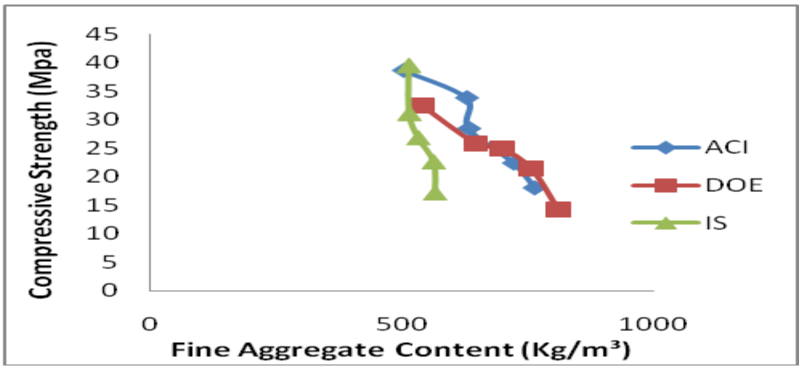

Figure 21: Compressive strength Vs fine aggregate content for 14 days curing period

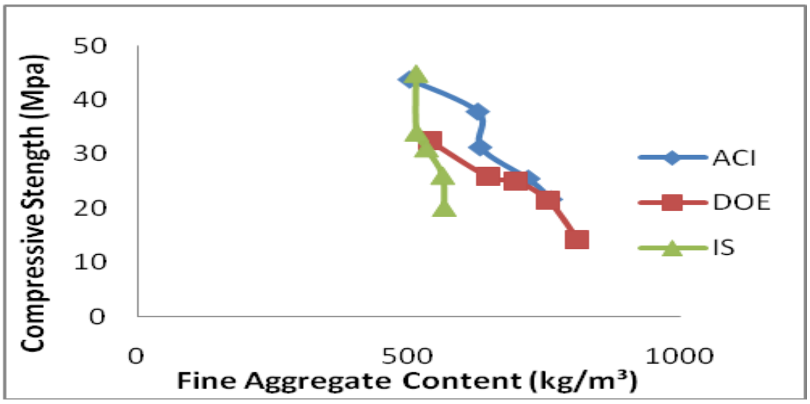

Figure 22: Compressive strength Vs fine aggregate content for 21 days curing period

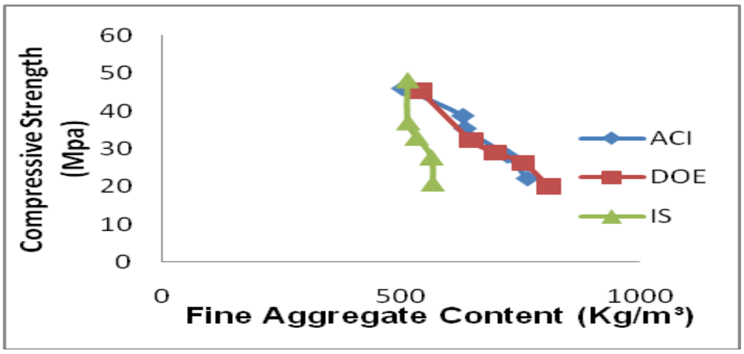

Figure 23: Compressive strength Vs fine aggregate content for 28 days curing period

Relationship between compression strength and coarse aggregate content

Figures 24, 25, 26 and 27 showed the relationship between the compressive strength and the coarse aggregate content of the concrete for the various curing periods. The coarse aggregate content for the ACI method remained relatively constant throughout the curing days for 7,14,21 and 28 days respectively. The ACI method had the lowest coarse aggregate content compared to the DOE and IS methods. This indicated that the ACI method is more economical than the IS and DOE methods because less materials were utilized to achieve desired results. "The compresive strength of concrete may increase along with an increase in coarse aggregate content up to a certain volume of aggregate and then decrease. The initial increase is due to the reduction in the volume of voids with the addition of coarse aggregate" (Konsul and Darwin, (1997)). This is why the DOE method showed a remarkable increase in compressive strength despite the increase in the coarse aggregate content. On the other hand a higher compressive strength seen in the ACI and IS methods was due to the reduction in coarse aggregate content, could be attributed to the fact that, lower coarse aggregate required less water to produce a workable mix. Less water means less voids in the concrete and resulted in higher compressive strength (Ejiogu *et al.*, 2018).

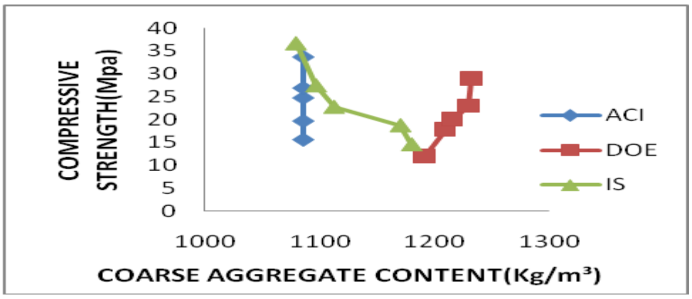

Figure 24: Compressive strength vs coarse aggregate content for 7 days curing period

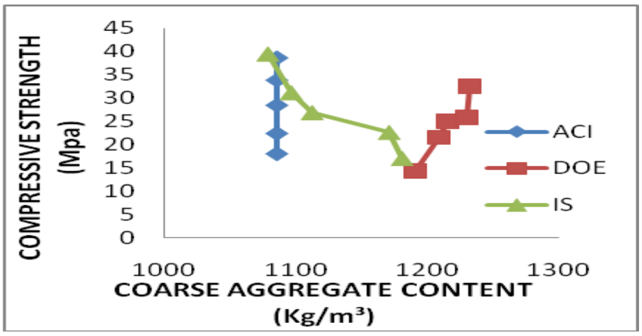

Figure 25: Compressive Strength vs coarse aggregate content for 14 days curing period

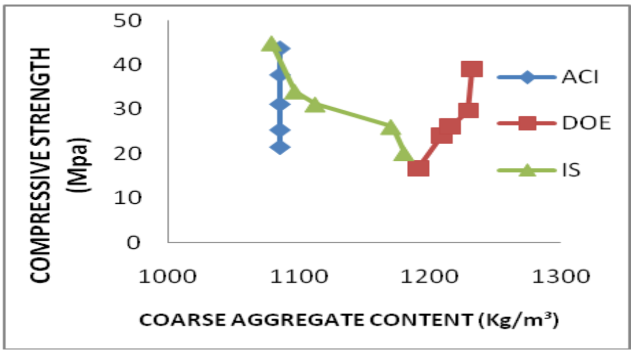

Figure 26: Compressive strength vs coarse aggregate content for 14 days curing period

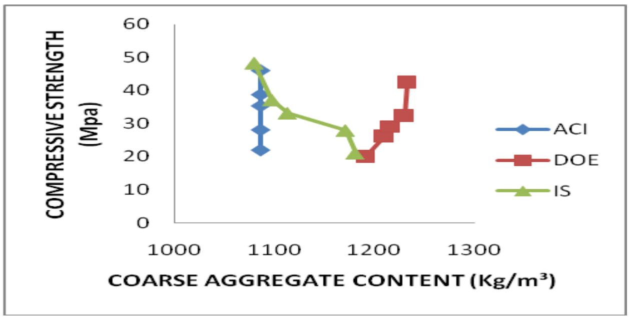

Figure 27 : Compressive strength vs coarse aggregate Content for 28 days curing period

Cost evaluation of the different mix proportions

50 kg of cement cost N2,200 (OPC 43 Grade), 1 Kg of cement will cost N44.00 ($0.088).

50 Kg of Fine Aggregate Cost N350, 1 Kg of Fine Aggregate will cost N7.00 ($0.014).

50 Kg of Coarse Aggregate N50, 1 Kg of Coarse Aggregate will cost N10 ($0.02).

The prices of the various mix design are represented in the Table 9. It showed that the most expensive mix method was the IS method because it utilized the highest cement content in the concrete mix for all the gardes of concrete produced. The cost of the ACI method was cheaper than that of the IS method for the M15, M20, M25, M30 and M40 concrete grade by 14.94%, 12.18%, 12.55%, 12.93%, and 4.10% respectively. The ACI method proved to be the most economical method compared to the IS method, since it met the TMCS with lower cost. The ACI method of mix design was cheaper than the DOE method for the M15 and M20 grades of concrete by 3.36% and 1.46% respectively. Subsequently the ACI method became sligthly more expensive than the DOE method for the M25, M30 and M40 grades of concrete by 2.93%, 1.25%, and 5.14% respectively. The DOE method did not meet the TMCS for all the grades of concrete produced (Table 7), however; may still be utilized for concrete mix proportioning only if the required strength of concrete is sufficient for the structure(s) to be constructed, but in concrete tehnology; concrete experts will always go for concrete that not only meet the required strength, but also the TMCS so that quality, durability and integrity of the concrete structure(s) will be not be compromised (Shetty, 2005). This puts ACI method of mix design at the top of the food chain, as it has proved to be the most efficient and economical method of proportioning concrete compared to the other two proportioning design methods.

Table 9: Cost implication of ACI, DOE and IS mix design proportion methods

S/N	Grade of Concrete	Cost Implication (N) For 1m^3 of Concrete ACI Materials	Kg	Cost (N)	DOE Materials	Kg	Cost (N)	IS Materials	Kg	Cost (N)
	M15	Cement	262.80	6537.30	Cement	253.00	6299.58	Cement	383.32	8027.74
		FA	763.08	3022.44	FA	810.70	3212.05	FA	566.00	2241.36
1.		CA	1085.80	5169.36	CA	1190.89	6741.06	CA	1180.00	6678.80
				∑14,729.10			∑16, 252.69			∑16,947.90
	M20	Cement	311.11	7748.54	Cement	287.67	7162.73	Cement	399.17	9938.96
2.		FA	721.35	2858.30	FA	756.73	2996.97	FA	563.31	2232.87
		CA	1085.80	6146.70	CA	1209.11	6842.94	CA	1170.76	6622.20
				∑16,753.60			∑17, 002.64			∑18,794.03
	M25	Cement	400	9961.60	Cement	338.71	8436.23	Cement	504.21	12556.71
3.		FA	632.45	2515.87	FA	698.15	2764.91	FA	533.02	2111.18
		CA	1085.80	6146.76	CA	1215.49	6879.73	CA	1112.63	6293.92
				∑18,624.23			∑18, 080.87			∑20,961.81
	M30	Cement	420.0	10459.68	Cement	375.00	9339.00	Cement	532.22	13252.89
4.		FA	627.93	2487.57	FA	646.68	2561.15	FA	515.18	2040.43
		CA	1085.80	6146.76	CA	1229.55	6958.97	CA	1096.89	6209.02
				∑19,094.01			∑18, 859.12			∑21502.34
	M40	Cement	560.0	13946.24	Cement	477.27	11886.00	Cement	563.22	14025.48
5.		FA	502.04	1986.66	FA	539.30	2139.48	FA	514.04	1986.66
		CA	1085.80	6146.76	CA	1232.25	6975.95	Ca	1079.21	6107.14
				∑22,079.66			∑21, 001.43			∑22, 119.28

Note: The calculations were based on the current price of the concrete materials at the time this study was done, the location and the Dollar rate (these prices are subject to fluctuations). Location: Ahmadu Bello University, Department of Chemistry, Zaria, Samaru, Kaduna State, Nigeria. Date; 12th December, 2016. Dollar rate adopted was based on the market rate at the time the study was done. Weight per unit volume of materials of concrete were taken from (Table 7) Mix proportions Design Methods.

CONCLUSIONS

The results showed that the ACI and the IS methods met the TMCS, while the DOE method did not meet the TMCS for all the grades of the concrete produced. The reason why the DOE method did not meet the TMCS could be attributed to the following reasons; higher water content, higher water cement ratio, lower cement content, higher aggregate to cement ratio, higher air voids and porosity in the concrete compared to the other two methods. The DOE method was cumbersome to proportion compared to the other two methods.

The cost implication for the different mix proportions showed that the most expensive mix design proportioning method was the IS method, due to the high cement content utilized for the concrete mixture. However the ACI method proved to be the most economical method of proportioning the concrete compared to the other two methods because it met the TMCS for the M15. M20, M25, M30 and M40 grade of concrete at the least cost. Conclusively the ACI method was the most efficient method of proportioning concrete compared to the other two methods. It was easy to design and apportion with (out) the use of admixtures and it met the required TMCS at the least cost. The author(s) thus, recommend that the ACI proportioning mix design method be adopted for proportioning concrete.

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REFERENCES

ACI 211. (1991). Standard practice for selecting proportioning normal, heavyweight and mass concrete. ACI Education Bulletin E1-91, 1(2), 1 - 8. Retrieved from https://pdfs.semanticscholar.org/ad80/1b522c5e725056a5a90d7d00bfa20356384a.pdf

Adewole, K. K., Olutoge, F. A. and Habib, H. (2014). Effect of Nigerian Portland-Limestone Cement Grades on Concrete Compressive Strength. International Journal of Civil and Environmental Engineering. 8 (11).

Afsar, J. (2012). Effects of aggregates on strength of concrete. Engineering Intro. Retrieved on December 2016 from http://www.engineeringintro.com/concrete/concrete-strength/effect-of-aggregates-on-strength-of-concrete/

ASTM C 33. (1997). Standard specifications for aggregates. ASTM International, 1 - 7.

ASTM D 75. (2003). Standard practice for sampling aggregates, ASTM International, 1 - 5.

Baskaran, K. and Gopinath, K. (2012). Study on applicability of ACI and DoE mix design methods for paving blocks. Annual Transactions of IESL, 127 - 134.

Chandrakar, J. K. and Mishra, S. P. (2012). Comparison of IS, BS and ACI methods of concrete mix design and proposing function equations based design.

Ejiogu, I. K., Mamza, P. A., Nkeonye, P. O. and Yaro, S. A. (2018). Effect of water-cement ratio and cure days on the strength and workability of normal concrete blocks. International Journal of Innovative Scientific and Engineering Technologies Research, 6(2), 11–18. https://doi.org/10.1029/WR024i007p01011.

Konsul, R. and Darwin, D. (1997). Effects of aggregates types, size and content on concrete strength and fracture energy (The National Science Foundation Research Report MSS-9021066). Retrieved from the U. S Department of Transportation website: www2.ku.edu/~iri/publications/sm43.pdf

Mehta, K. P. and Burrows, R. W. (2011). Building durable structures in the 21st century. Concrete International, 2000, 57 - 63.

Shetty, M. (2005). Concrete technology (10th ed). Ram Nagar, New Delhi: Chand, S., and Company LTD.